JOURNAL

OF THE

Elisha Mitchell Scientific Society,

1893

TENTH YEAR. FIRST PART.

JOURNAL

OF THE

ELISHA MITCHELL SCIENTIFIC SOCIETY,

VOLUME X—PART FIRST.

JANUARY—JUNE.

1893.

POST-OFFICE:

CHAPEL HILL, N. C.

E. M. UZZELL, STEAM PRINTER AND BINDER,
RALEIGH, N. C.
1893.

OFFICERS.

1893.

PRESIDENT:

JOSEPH A. HOLMES, - - - - - - - - Chapel Hill, N. C.

FIRST VICE-PRESIDENT:

H. L. SMITH, - - - - - - - - - - Davidson, N. C.

SECOND VICE-PRESIDENT:

J. W. GORE, - - - - - - - - - - Chapel Hill, N. C.

LIBRARIAN:

COLLIER COBB, - - - - - - - - - Chapel Hill, N. C.

SECRETARY AND TREASURER:

F. P. VENABLE, - - - - - - - - - Chapel Hill, N. C.

LIBRARY AND PLACE OF MEETING:

CHAPEL HILL, N. C.

TABLE OF CONTENTS.

PAGE.

Notes on the Forest Resources of North Carolina. W. W. Ashe.... 5

Notes on the Deflective Effect of the Earth's Rotation as Shown in Streams. Collier Cobb..... 26

The Stone Arch. William Cain, C. E. 32

JOURNAL

OF THE

Elisha Mitchell Scientific Society.

NOTES ON THE FOREST RESOURCES OF NORTH CAROLINA.

BY W. W. ASHE.

BOTANIC DIVISIONS.

North Carolina can be divided topographically into three fairly well-marked divisions:

1. An eastern or coastal plain region, extending inland from the coast a distance of one hundred to one hundred and fifty miles and having an aggregate area approximating 24,000 square miles. Its surface is that of a gently undulating plain of less elevation (ten to twenty feet above sea-level) and a more nearly level surface eastward, and becoming more elevated (three hundred to five hundred feet) and rolling along its western border. Its soil is generally a sandy loam or sand, though in limited areas clay predominates. In the more eastern portion of this region are numerous extensive swamps or marsh areas surrounding small lakes or bordering the streams. In some of these the soil is mainly an admixture of sand and vegetable mold, while in others it is a fertile loam. In this district the normal annual temperature is about 61° F., and the normal annual rain-fall about fifty-five inches.

2. A middle district, which extends westward to the Blue Ridge, two hundred miles beyond the coastal plain, and extends across the State parallel to it, having an area of about 22,000 square miles. In the east it is rolling, but towards the western border is rugged and hilly, and in places even mountainous, being penetrated by mountain spurs from the Blue Ridge. It has an average altitude of eight hundred and fifty to nine hundred feet, but rises at its highest peaks to a little over 3,000 feet, while along its extreme eastern border it is not over four hundred to five hundred feet. On the uplands the soil may be classed in general terms as a loam, which becomes sandy in some places and clayey in others. Along the streams there is usually a rich, dark-colored loam with an admixture of humus. This region has an average temperature of about 58.5° or 59° F., and an annual rain-fall of about fifty inches.

3. The western district is an elevated, mountainous region, with an average altitude of 3,500 feet, but rising (at Mt. Mitchell) to 6,711 feet. This region includes the Blue Ridge, which forms its general eastern boundary, and the Great Smoky Mountains, which border it on the west. Numerous cross ridges, separated by irregular valleys, connect these two mountain ranges. The area of the region is about 6,000 square miles. Though the mountain slopes are often steep, and the valleys quite narrow, the soil is exceedingly fertile, being a loam generally rich in organic matter. The average temperature for the counties of this western district probably approximate 50° F., varying from 57.8° at Hot Springs to an estimated temperature for the top of Mt. Mitchell of less than 38°,* and the normal annual precipitation is about fifty-seven inches.

There are three fairly well-marked botanic divisions coin-

*_Climatology of North Carolina_—N. C. Agr. Exp. Sta. Report. Raleigh, 1892; p. 166.

ciding in general with these topographic districts. The lower botanic division, however, extends a few miles west of the sandy coastal plain boundary line, and the third botanic division begins in the damp "coves" and the higher mountain spurs lying just east and south-east of the Blue Ridge.

It must not be inferred from the above statement that these botanic divisions are separated by any sharp lines on the two sides of which radically different conditions of soil and climate and vegetation exist, for while there are certain places where these conditions do change abruptly, generally such is not the case; but, on the contrary, these divisions are separated by what may be called transition zones, in which the conditions of the two adjacent regions commingle to a greater or less degree. Thus in the following counties we find transition conditions between the eastern and middle districts: Northampton, Warren, Vance, Franklin, Durham, Wake, Chatham, Moore, Montgomery, Richmond and Anson. And the tier of counties just east of the Blue Ridge may be regarded as the transition zone between the western and middle botanic districts. Here in the valleys we find physical conditions and plants such as characterize the middle district, and on the slopes of the higher ridges are found a climate and vegetation much like those of the mountain district.

These differences in topography and elevation, with accompanying differences in soil, corresponding in a general way to geological formations, have given this State a wonderful variety of woods, and have placed in juxtaposition trees normally separated by many degrees of latitude. Thus are found in North Carolina eight species of pines out of the thirteen given in the Tenth United States Census Report as occuring in the United States east of the Mississippi River; twenty oaks out of twenty-three; all of the six maples; three elms out of four; all seven magnolias;

five hickories out of eight, and four out of the six species of ash.

EASTERN DISTRICT.—The eastern or lower district, having its climate tempered by the near approach of the gulf-stream, has a decided southern or subtropical flora, as pronounced in the larger forest growth as among minor plants. The trees confined to this district, or but slightly entering the others, are: *Magnolia grandiflora L.** (Magnolia); *M. glauca L.* (Sweet Bay); *Prunus Caroliniana Ait.* (Mock Orange); *Bumelia lycioides Gært.; Gordonia Lasianthus L.* (Bull Bay); *Nyssa aquatica L.* (Black Gum); *N. uniflora Walt.* (Tupelo Gum); *Tilia pubescens Ait.* (Linn.); *Carya aquatica Nutt.; Planera aquatica Gmel.* (Planer Tree); *Quercus laurifolia Michx.* (Laurel Oak); *Q. cinera Michx.* (High Ground Willow Oak); *Q. virens Ait.* (Live Oak); *Q. aquatica Walter* (Water Oak); *Q. Catesbæi Michx.* (Turkey Oak); *Q. macrocarpa Michx.* (Mossy Cup Oak); *Q. lyrata Walt.* (Over Cup Oak); *Q. Michauxii Nutt.* (Swamp White Oak); *Pinus Australis Michx.* (Long-leaved Pine); *P. Taeda Linn.* (Rosemary, Loblolly, or Short-leaved Pine); *P. serotina Michx.* (Pond Pine or Savannah Pine); *Chamæcyparis sphæroidea Spach.* (Juniper or White Cedar); *Taxodium distichum Rich.* (Cypress); *Sabal Palmetto Todd.* (Palmetto).

MIDDLE DISTRICT.—In the middle section the prevailing growth is the hickories, oaks, elms, and short-leaved pines, common to all the Atlantic States, and these extend into the other sections and enter largely into the composition of their forests. The common trees through this district are *Magnolia umbrella Lam.* (Umbrella Tree); *Asimina triloba Dunal.* (Papaw); *Liriodendron Tulipifera L.* (Yellow Poplar); *Amelanchier Canadensis L.* (Sarvice);

*The names used in this paper are, with few exceptions, those given in Curtis' *Woody Plants of North Carolina*; Raleigh, 1860.

Cornus florida L. (Dogwood); *Gleditschia triacanthos L.* (Honey Locust); *Acer dasycarpum Ehrh.* (Silver Maple); *A. rubrum L.* (Red or Swamp Maple); *Negundo aceroides Mœnch.* (Box Elder); *Ilex opaca Ait.* (Holly); *Oxydendrum arboreum D. C.* (Sour Wood); *Nyssa multiflora Wang.* (Black Gum); *Diospyrus Virginiana L.* (Persimmon); *Fraxinus Americana L.* (White Ash); *F. pubescens Lam.* (Red Ash); *F. viridis Michx.* (Green Ash); *Sassafras officinalle Nees.* (Sassafras); *Platanus occidentalis L.* (Sycamore); *Ulmus fulva Michx.* (Slippery Elm); *U. Americana L.* (Elm); *U. alata Michx.* (Winged Elm or Wahoo); *Carya alba Nutt.* (Shell-bark Hickory); *C. tomentosa Nutt.* (Hickory); *C. glabra Torr.* (Pig Nut); *C. microcarpa Nutt.; Juglans nigra L.* (Black Walnut); *Quercus phellos L.* (Willow Oak); *Q. nigra L.* (Black Jack); *Q. tinctoria Barr.* (Black Oak); *Q. coccinea Wang.* (Scarlet Oak); *Q. falcata Michx.* (Spanish Oak); *Q. obtusiloba Michx.* (Post Oak); *Q. alba L.* (White Oak); *Fagus ferruginea Ait.* (Beech); *Carpinus Americana Michx.* (Hornbeam); *Ostrya Virginica Willd.* (Iron Wood, Hop Hornbeam or Water Beech); *Betula nigra L.* (Black Birch); *Salix nigra Mars.* (Willow); *Populus angulata Ait.* (Cotton Wood); *P. heterophylla L., P. monilifera Ait., Pinus mitis Michx.* (Short-leaved Pine); *P. rigida Mill.* (Pitch Pine); *Juniperus Virginiana L.* (Red Cedar).

MOUNTAIN DISTRICT.—In this district occur, as characteristic forest trees: *Magnolia acuminata L.* (Cucumber); *M. macrophylla Michx.* (Magnolia); *M. Frazeri Walt.* (Wahoo); *Prunus serotina Ehrh.* (Wild Cherry); *Robinia Pseudacacia L.* (Locust); *R. viscosa Vent.* (Clammy Locust); *Cladrastis tinctoria Raf.* (Yellow Wood); *Ilex monticola Gray; Fraxinus Americana Linn.* (White Ash); *Æsculus flava Ait.* (Buckeye); *Tilia Americana L.* (Linn.); *T. heterophylla Vent.* (Linn.); *Halesia tetraptera L.* (Snowdrop Tree); *Stuartia pentagyna L'Her.; Betula lutea Michx.*

(Yellow Birch); *B. lenta L.* (Sweet Birch); *Quercus imbricaria Michx.* (Water Oak); *Q. rubra L.* (Red Oak); *Q. prinus L.* (Chestnut Oak); *Castanea vesca L.* (Chestnut); *Populus grandidentata Michx.* (Aspen); *Pinus pungens Michx.* (Table Mountain Pine); *P. Strobus L.* (White Pine); *Abies Fraseri Lindl.* (Balsam Fir or She Balsam); *Tsuga Canadensis Carr.* (Hemlock); *T. Caroliniana Engel.* (Hemlock); *Picea nigra Link.* (Black Spruce or He Balsam).

In addition to the above there are to be found in one or more of the botanical divisions of the State over two hundred minor trees, shrubs and vines of more or less value for fruit culture or floriculture, etc. There are four species of grape (*Vitis aestivalis*, *V. labrusca*, *V. vulpina*, *V. cordifolia*), from the first three of which cultivated varieties have sprung. There are also found in these several sections of the State several hundred herbs, various parts of which are extensively used for medicinal purposes, a discussion of the more important of which will appear in a future number of the JOURNAL.

ECONOMIC WOODS.

In the above statement a small number of the trees named as occurring in the different regions have timber of but little value, owing to a lack of strength and durability, and are of such small size as to have little economic value, and there are a few others of such infrequent occurrence as to be commercially unimportant. But in each region there are many valuable forest trees, and the following notes will contain a brief statement of their distribution, abundance, size, and uses:

Magnolia acuminata L. (Cucumber): Two to four feet in diameter, eighty to one hundred and twenty feet high. Frequent in the upper district with Yellow Poplar. Not over 5,000,000 feet standing in the fifteen counties through which its distribution extends. Has the same use as Yellow Poplar.

M. Fraseri Walt. (Wahoo) is a small tree, one to two feet in diameter. Very common in western district; used medicinally, rarely for lumber; very ornamental.

Liriodendron Tulipifera L. (Yellow Poplar): Four to eight feet in diameter, one hundred to one hundred and twenty feet high. Occurs in all districts; very common in western. Lumber is used in building very extensively, for interior wood-work and cheap furniture. The chief bodies standing are in Watauga, Yancey, Mitchell, Swain, northern Graham, Macon, Jackson, Transylvania, Wilkes and Alleghany. Altogether there is 50,000,000 feet of poplar lumber in these counties. The trees have been removed adjacent to the large rivers and around towns, as it is the building material of this section. Still abundant in the western tier of the midland counties, except along the railroads.

Tilia Americana L. (Linn.): A middle-sized tree, frequent in the higher mountains and mixed with *T. heterophylla Vent.* (Linn.), which is very common throughout the mountains, except around thick settlements, where it has been cut in winter, so cattle could feed upon its buds. Very abundant in Swain, Jackson, Macon, Transylvania, Yancey, Mitchell, Watauga and Ashe. The wood is light, soft and white; rarely sawn for ceiling. It is useful for making paper.

T. pubescens Ait. (Linn.): Very frequent in rich alluvial places along the coast. Same uses and character as the above species, but smaller.

Æsculus flava Ait. (Buckeye): Very abundant as a large tree on damp soil throughout the mountain district. It is not used commercially except around Bryson City, Swain county, where it is manufactured into excelsior.

Acer saccharhinum Wang. (Sugar Maple or Sugar Tree): Very common throughout all mountain counties, where it reaches a height of ninety to one hundred feet and a diame-

ter of three to four feet; and it is found also in the swamps of Pender and Onslow and in low grounds of other eastern counties. It has been cut to a small extent for flooring and furniture, and in the northern counties small quantities of sugar are made from the sap.

A. dasycarpum Ehrh. (White or Silver Maple): A small tree, rarely more than two feet in diameter, sparsely distributed in all portions of the State, usually in moist places; more abundant in the mountain counties.

A. rubrum L. (Red or Swamp Maple): Tree two to three feet through and rarely sawn, and then for ceiling; abundant, especially in moist places, in all portions of the State.

Robinia Pseudacacia L. (Yellow Locust): Once very common through the mountain counties, though it has been very largely used up for posts in thickly settled regions. It is still widely distributed and abundant in Rutherford, Polk and other south-western counties, and occurs sparingly in the middle district. In Haywood and Swain there are factories making from it insulating pins for telegraph poles. The trees are one and one-half to two and one-half feet in diameter; sixty to eighty feet high. The wood is yellow, hard, and resists exposure and decay.

Cladrastis tinctoria Raf. (Yellow Wood): A small tree, one and one-half feet in diameter; forty to sixty feet high, with a deep yellow hard wood; it is mostly confined to rich "coves" of Graham, Macon, Clay and Cherokee counties, but is very frequent through these. It has been used in Cherokee county for making furniture.

Prunus serotina Ehrh. (Wild Cherry): Occurs all over the State, but only in the mountain counties does it reach sufficient size and abundance to become a valuable timber tree. There in rich, cold "coves" it becomes a tree two to four feet in diameter and eighty to one hundred feet high. It is a fine-grained, medium hard, red wood, taking a fine

polish; largely used for furniture and interior work of all kinds, and is one of the first trees removed, when easily accessible, on account of its high value. Large quantities of it still remain in certain regions, as in the north-western part of Ashe county and around Grandfather, Beech and Roan mountains. About the head-waters of Caney river there are probably 1,000,000 feet standing; in north Swain, especially on Ocona-Lufty River, about 3,000,000 to 4,000,000 feet; small quantities are found in other mountain regions; and in the north "coves" of the east-slope of the Blue Ridge there is still some cherry timber remaining.

Amelanchier Canadensis L. (Sarvice): Occurs abundantly in the mountains, where it is a small tree, and is used there in turneries in some of the towns.

Hamamelis Virginica L. (Witch Hazel): A shrub or small tree, very common throughout the middle and upper districts. It is use medicinally.

Liquidambar Styracifolia L. (Red or Sweet Gum) is common throughout the middle and lower districts, becoming in the swamps and low grounds of the latter a very large tree, four to five feet in diameter and ninety to one hundred feet high. It forms with cypress and black gum about one-half of the growth of the deeper swamps in many portions of the eastern counties, and has been cut out in only a few places, as around Bladenboro, Wilmington, Newbern, Goldsboro, Hub, and in limited portions of Northampton, Perquimans, Pasquotank and Camden counties. The wood is hard and heavy, fine-grained, red; used for furniture.

Cornus florida L. (Dogwood) is common over the whole State. It is a small tree, with hard, compact, white wood; has been largely removed in many portions of the middle district, around larger towns, for shuttle-blocks, etc.

Nyssa multiflora Wang. (Black Gum): A middle-sized tree, found all over the State, in all soils. Its wood is very compact, with fibers interwoven, and is rarely used, except occasionally for hubs, mallets, etc.

N. aquatica L. (Black Gum) is a very large tree, four to five feet in diameter, common throughout deep swamps of the lower district. The wood and its uses are much the same as *N. multiflora.*

Nyssa uniflora Walt. (Tupelo Gum): A medium-sized tree, common in deep swamps in the section along and south of Neuse river. Its wood is very light, white, but with fibers interwoven as in the other species, and hence is very difficult to split, tasteless; used for wooden-ware of all kinds. Very little has been removed and only in a few counties.

Oxydendrum arboreum D. C. (Sour Wood) is a small tree, very common through mountains and the middle district. Its wood is firm, fine-grained and of reddish color, and is being used for making certain parts of furniture—chair rounds and legs, newel posts, balisters, etc.

Kalmia latifolia L. (Ivy): A large shrub, very common in mountains, growing generally in dense thickets; its matted roots, forming large "stools or burls," are gotten out around Cranberry, Elk Park, Magnetic City, and in several counties south of the French Broad river, and used for making tobacco pipes, handles, etc., and the branches are used for rustic furniture. The wood is hard and fine-grained.

Ilex opaca Ait. (Holly) is a small tree one to two and one-half feet in diameter; common in wet, sandy soils of lower district, but found also in the other districts. The wood is very fine-grained and white; it has been largely removed in the north-east counties, but has not been touched in the south-eastern counties.

Diospyros Virginiana L. (Persimmon): A small tree with very hard, tough wood. It is common through the eastern and middle counties, but has been largely removed from Wilkes, Surry, Caldwell, McDowell, Lincoln, Catawba, Guilford, Forsyth and Union counties, being used in the manufacture of shuttle-blocks.

Fraxinus Americana L. (White Ash) was once common in wet or damp places over the entire State. A large tree two to four feet in diameter and eighty to one hundred feet high. Its wood is white, very elastic, and strong; and in the western counties it is used for making wagons, furniture, and especially the curled wood. In the eastern counties it is used for oars, barrel heads, and lumber. In the middle district it is used for making paper and lumber and furniture. It has largely been removed from the following mountain counties: Ashe, west Yancey, south Madison, Buncombe, Haywood, north Jackson and north Macon, Graham (except along Tuskeegee creek), Cherokee and Henderson. Has been removed in middle district when accessible to railroads and larger streams.

F. platycarpa Michx. (Water Ash) is abundant in many of the larger swamps of lower district, to which it is confined. The counties of Pender, Sampson, Hyde and Pamlico still have very large bodies, but it has been removed where turpentine orchards have been worked.

F. viridis Michx. (Green Ash) and *F. pubescens Lam.* (Red Ash) are middle-sized trees, found only in middle district and used for lumber and making paper. Along lines of transportation they have been largely removed, but in inaccessible places they are still abundant.

Carya alba Nutt. (Shag-bark Hickory) is frequent in the middle and upper districts.

C. amara Nutt. (Bitter-nut Hickory) is common in wet places in the upper districts.

C. glabra Torr. (Pig-nut Hickory) abounds in dry soils in all portions of the State.

C. tomentosa Nutt. (Common Hickory) is very common in dry soils through the lower and middle districts.

All of these hickories have been cut away, more or less, around towns for fire-wood, and for the manufacture of spokes, handles, and wagon material, especially around large towns in the middle district.

Juglans nigra L. (Black Walnut) is largely removed in all mountain counties, except Wilkes and Madison and in a few other counties where it has been especially preserved on limited areas; and in neither of these counties is it very abundant, though there are many trees of large size. It is also found occasionally in many counties of the middle and lower districts, at a distance from means of transportation, but it is there a tree of medium size.

J. cinera L. (Butter Nut) is frequent in most mountain counties and extends but a short distance below the mountains. The curly wood is used for furniture and interior finish.

Quercus alba L. (White Oak) and *Q. obtusiloba Michx.* (Post Oak) are common over the whole State except in the extreme east, although they have been largely removed in middle district for fuel, cross-ties, wagon material, staves and lumber. But large quantities yet remain, and a vigorous second growth of equal density and strength to the original is coming on, so that it appears that there will be an abundance of both at all times over the larger part of the State.

Q. Tinctoria Bartr. (Black Oak), *Q. coccinea Wang.* (Scarlet Oak), and *Q. falcata Michx.* (Spanish Oak) are all most abundant in the middle district on dry soil. They are generally not used where good white oak can be obtained; rarely used for staves and wagon material; more frequently for fence rails, furniture and clap-boards.

Q. macrocarpa Michx. (Mossy-cup Oak), *Q. Lyrata Walt.* (Over-cup Oak), and *Q. Michauxii Nutt.* (Swamp White Oak) all occur in swamps of the eastern section, and where contiguous to large turpentine orchards have been used for staves, and they are also used to some extent for rails, clap-boards, etc.

Q. laurifolia Michx. (Laurel Oak) and *Q. aquatica Cates.* (Water Oak) are trees still very common in lower districts,

where they are rarely used, except for rails, the timber being open and porous.

Q. Rubra L. (Red Oak) occurs in the cool, fertile soils of the middle and mountain districts, and sparingly in the eastern counties. It reaches, under favorable conditions, a diameter of four feet and a height of seventy to eighty feet; the wood is reddish, open, and rather coarse grain, but strong, and is used extensively for clap-boards, cooperage, and articles of furniture.

Q. imbricaria Michx. (Water Oak, Laurel Oak or Shingle Oak) is infrequent, occurring only in counties west of the Blue Ridge; a medium size tree, with rather open, porous wood, rarely used, where better material can be obtained, for clap-boards, staves, etc.

Q. Prinus L. (Chestnut Oak) is common on dry ridges through mountain and more elevated parts of the middle section. It is used for furniture, wagon material, and the bark is used for tanning. It has been largely removed around Cranbury, Asheville and Morganton.

Castanea vesca L. (Chestnut) is very abundant through all mountain regions and is found sparingly in some of the Piedmont counties, though the best trees have in many places been removed for rails. It is sawn for lumber at Dillsboro and Asheville, and has been removed largely from Graham, Ashe and Buncombe counties.

Populus grandidentata Michx. (Poplar), *P. heterophylla L.* (Cotton Wood), *P. angulata Ait.* (Cotton Wood), and *P. monilifera L.* (Cotton Wood): All except the first occur frequently in lower or middle districts, though in the neighborhood of turpentine orchards they have been used for making barrel heads. The first named species is confined to the upper part of the middle district.

Of the eight pines occurring in this State five are of the first economic importance. They are *Pinus Strobus L.* (White Pine), *P. australis Michx.* (Long-leaved Pine),

P. Taeda L. (Short-leaved or Old Field Pine), *P. rigida Mill.* (Black Pine), and *P. mitis Michx.* (Short-leaved or Yellow Pine). *P. serotina Michx.* is very rarely used. *P. pungens* and *P. inops Ait* are practically worthless for timber purposes.

P. Strobus L. (White Pine) extends in a narrow belt along the Blue Ridge from southern Ashe to Macon, also occurs in Graham, north Haywood, and adjacent parts of Madison, and in northern Madison and western Mitchell. It is locally used for shingles. Has been removed only around Marion, in parts of Jackson, Transylvania and Macon counties.

P. australis Michx. (Long-leaved or Turpentine Pine) extends over a large part of the sandy land of the lower district, but occurs only sparingly north of Roanoke river and west of Wake and Richmond counties. It formerly existed as a pure forest over the sandy lands of this area. But the inroads which have been made through it for the past century to supply naval store products, ship timber and building material have removed or destroyed most of the forest adjacent to the railroads and immediately along the larger water courses. The largest bodies still standing are in Montgomery, Sampson, Robeson, Harnett, Cumberland, Johnston and Richmond counties. Large bodies of virgin pine forest are rare except along the extreme western border of the pine belt.

P. Taeda L. (Rosemary, Loblolly, Short-leaved or Old Field Pine) is found over the whole of the eastern district, but growing originally on wet clay lands and often forming considerable clumps in small swamps. When the long-leaved pine is removed this species takes its place on the sandy land and is there called old field pine. In its original growth in swampy places it is decidedly the largest pine in the State, having a height of one hundred to one hundred and twenty feet and a diameter of from three to five feet. Here it has a fine, even grain, heart very large,

with but little resin, and a strong, durable wood. The high price paid for large stocks for ship material causes its removal where accessible, even in advance of *P. australis;* but it is still abundant where transportation facilities at present are not suitable for its removal. Its second growth on dry, sandy land is a smaller tree, sappy, with very coarse grain, and little or no heart, the wood decaying rapidly on exposure; but as it makes a beautiful wood for interior finish it is largely sawn around large towns and kiln-dried for that use. The general character of the trees growing on dry, sandy soils is so different from that of those growing about the wet lands that the two trees are usually (though erroneously) believed by lumbermen to belong to different species.

P. serotina Michx. is common over wet lands in the southeast counties and is sometimes sawn with *P. Taeda;* but the lumber is gummy and of poor quality.

P. mitis Michx. (Short-leaved or Yellow Pine), formerly common over the whole area of the middle district and extends through the southern part of the mountain district, being mixed with deciduous trees. It has been largely removed for lumber around the larger towns and thick settlements, and along the lines of the railways; and through Catawba, Lincoln and Gaston counties large quantities of it have been cut and used for making charcoal. Wilkes, Caldwell, Alexander and Rutherford counties contain the finest bodies of this timber to be found in the middle district. This tree frequently reaches two to three feet in diameter and seventy to eighty feet high.

P. rigida Mill. (Black or Pitch Pine) is a tree slightly smaller than the preceding and making inferior lumber, but largely used along with it. Surry, Wilkes, Caldwell, Burke, McDowell and Polk counties contain the larger part of what is known to occur east of the Blue Ridge; but there is also a great deal in the mountain counties south of the French Broad river.

Tsuga Canadensis Carr. (Hemlock) is a large tree; abundant in moist regions through nearly all of the mountain counties. It has only been removed in northern Mitchell, where it has been barked for tanning purposes, and along the Little Tennessee river.

T. Caroliniana Engel. (Hemlock) is frequent on ridges along the Blue Ridge from eastern Ashe to Macon. It has been cut in only a few localities, for frames for houses, etc.

Picea nigra Link. (Black Spruce or He Balsam) forms twenty square miles of virgin forest in Watauga, Mitchell, Yancey, Haywood and Swain counties. Has been cut only in some places about Roan mountain. It is a tree of three feet in diameter and sixty to ninety feet high.

Abies Fraseri Lindl. (Balsam, or She Balsam) covers the summit of the highest mountain peaks.

Chamæcyparis sphæroidea Spach. (Juniper or White Cedar) occurs in many of the large swamps in the eastern district, especially in Harnett, Tyrrell, Gates and most of the other extreme eastern and north-eastern counties. It has been largely removed from Pasquotank, Perquimans and Camden counties, and about the larger eastern towns. It is a medium-sized tree and is very valuable for making pails, tanks, boats, shingles, etc., for which purposes it is largely used.

Taxodium distichum Rich. (Cypress) occurs abundantly in the swamps of the eastern section. It has been worked up around larger towns and in the north-eastern counties of Currituck, Perquimans, Hertford and Camden. It is a very large tree, four to five feet through and from eighty to more than one hundred feet high. Its wood is light, and is used largely for lumber, shingles and boats, and to a small extent for furniture.

Sabal Palmetto Lodd. (Palmetto) occurs somewhat abundantly on Smith's Island, at the mouth of the Cape Fear river. It is a small tree about one foot

in diameter and thirty or forty feet high. It has been found to serve an excellent purpose for piling, and this is about the only use to which it has been put.

Juniperus Virginiana L. (Red Cedar) is a common but rather small tree throughout the State, but most abundant in the south-eastern counties. It is used mainly for boxes and posts.

TRANSPORTATION FACILITIES.—Railroads penetrate the State in every direction, there being but few counties which are not touched by them. For marine shipment material from all north-eastern counties goes readily by way of Norfolk. For counties drained by the Tar and Neuse Newbern is the natural shipping point, while for the whole southern and central sections Wilmington is the central point, vessels drawing over twenty feet being able to enter its harbor.

ACCESSIBILITY OF EXISTING FORESTS.—While there is no large body of timber in the State valueless on account of its inaccessibility, there are many so situated that removal is not feasible with the existing means of transportation. But the experience of the past ten years is sufficient to prove that these large bodies of virgin forests to be found in the State will be penetrated by railroads in the near future, as the demand for the timber increases. The hard wood forests in some of the counties west of the Blue Ridge are naturally tributary to Tennessee, and the timber in the form of logs is being removed by floating down the creeks and rivers with the aid of flood dams. Many of these mountain streams are of sufficient size and rapidity to afford ample means for logging. East of the Blue Ridge tracts not adjacent to large streams or railroads are being reached by short timber roads. A number of such roads are now in operation and others are being constructed. In the eastern district, on pine lands where the country is flat, wooden and iron tramways are laid to be operated by horse-

power or narrow guage steam engines. In the eastern swamps, to get at the cypress, white cedar and other trees, the plan adopted by larger companies is to dig canals by hand or with dredges parallel to the drainage streams of the swamps. The logs are floated through these canals to some central point and there worked up.

FOREST MANAGEMENT.

Up to within the past few years forest management in North Carolina was deemed quite a useless business, but lately prudent individuals have placed large estates under foresters, one of whom was trained in European schools of forestry. As yet, however, this is little more than an experiment.

During the past two years the North Carolina Geological Survey has made a careful examination of the forests of the State with a view to the inauguration of modern methods of forest management, and the securing of such laws as will best encourage forest protection and improvement.

During the present year (1893) the Survey, recognizing the fact that the long-leaved pine (*P. palustris Miller, or P. australis Michx.*), a most valuable tree in this State, does not, under the existing conditions, extensively reproduce itself, has begun an examination of the causes operating against its increase and means by which it can be planted and economically cultivated, so as to make use of the waste lands formerly entirely occupied by this tree but now barren or covered with the loblolly pine (*Pinus Tadea L.*). Experiments are now under way for the purpose of determining the relative fertility of its seed as compared with those of other pines; causes why other species are so widely disseminated over cleared lands, while the long-leaved pine does not appear to be so; methods of planting, raising and protecting young pines; insects and fungous ene-

mies, and the damage done to the young pines by hogs, cattle, fires, etc.

WOOD-WORKING ESTABLISHMENTS.

A few facts, taken largely from the "Hand-Book" of North Carolina,* concerning wood-working establishments should be stated in this connection. Although little of the lumber sawn in North Carolina, other than for buildings, is worked up in the State, yet the number of wood-working factories is constantly on the increase. The most numerous concerns are manufactories of carriages and buggies. "Of these Alamance county has two, Alexander two, Ashe one, Beaufort one, Bertie three, Caldwell one, Chatham one, Cleveland one, Cumberland two, Davidson two, Durham one, Forsyth six, Gates two, Guilford two, Haywood one, Halifax one, Hertford three, Lenoir two, Lincoln two, Moore two, Pasquotank one, Randolph two, Sampson two, Vance one, Wake one, Warren three, Washington three, Wilkes two, Wilson one, Yadkin four—in all fifty-eight, established in thirty out of the ninety-six counties of the State, and representing every section in it. Among them there is wide range of excellence, defined and governed largely by experience and time. Many of them are new, the product of the new industrial revolution. A few are old and are meritorious, not only for the character of the work done by them, but because of the courage and foresight which gave them existence far in advance of similar enterprises in the State.

"Not less important, and of much wider application, is the manufacture of wagons, carts, etc., conducted by thirty-two different establishments in almost the same number of counties, as follows: Alamance has one, Alexander two, Anson three, Cabarrus one, Caldwell one, Catawba one,

**Hand-Book of North Carolina*—Raleigh, 1893, pp. 273-275.

Clay one, Cleveland one, Cumberland two, Pamlico one, Pender one, Rutherford one, Surry one, Stanly one, Wake three, Yadkin one. One of the largest of these is at Waughtown, near Winston-Salem, founded in 1834. Another large one is at Hickory."

"Of furniture factories, there are twenty-five, of which one is in Ashe, three in Buncombe, one in Davie, two in Forsyth, one in Gaston, two in Guilford, one in Henderson, three in Lincoln, one in Macon, one in Martin, one in Mecklenburg, one in Montgomery, one in Moore, two in Rowan, one in Surry, one in Wake, one in Wayne, and one in Yadkin.

"For the making of hubs, spokes, and handles there are six factories, viz.: Bertie has one, Guilford one, Mecklenburg one, Montgomery one, Rowan one, Rutherford one.

"Of sash, door and blind factories there are twenty-four, viz.: Buncombe has two, Burke one, Cabarrus one, Caldwell one, Catawba two, Davidson two, Durham one, Forsyth one, Gaston one, Guilford three, Johnston one, Rowan three, Stanly one, Surry one, Wake two, Wilkes one.

"Of another variety of wood-working factories is that at Newbern for the manufacture of plates and dishes made out of sweet-gum, and also berry baskets.

"At Wilmington a somewhat similar establishment was operated by steam and employed one hundred and twenty-five people. The material chiefly used is gum logs, and the product is butter plates and baskets, berry baskets and crates.

"Of the other simpler and ruder establishments for the conversion of the product of the forest there are, as nearly as can be ascertained, in operation in the State one hundred and fourteen steam saw-mills, eighty turpentine distilleries (undoubtedly below the actual number); and, as largely connected with the products of the forest, a very large

number of tanneries, the best and largest equipped of which is the one at Morganton, constructed and conducted on the most advanced scientific application of theory to intelligent practice.

"In connection with paper manufacture it may be said that originally using only the waste of textile fabrics, the immensely increased consumption of paper demanded other raw material, for the supply of which human ingenuity was heavily taxed. The additional material has been found in wood-pulp, mechanically or chemically prepared. The abundance in North Carolina of soft woods suitable for such purposes has led largely to the combination of wood-pulp with cotton, flaxen and hempen fiber; and the factories now in operation in the State are able to supply as good a material for book, printing and wrapping paper as can be made elsewhere. There are three principal paper-mills in North Carolina—that at Salem, in Forsyth county, at Falls of the Neuse, in Wake county, and at Long Shoals, in Lincoln. The product of these mills is bristol-board, writing paper, book and newspaper, and wrapping paper of all kinds."

NOTE.—On page 6, six lines from the bottom, "approximate" should read approximates. And on page 11, eleven lines from the top, "50,000,000" should be 500,000,000.

NOTES ON THE DEFLECTIVE EFFECT OF THE EARTH'S ROTATION AS SHOWN IN STREAMS.

BY COLLIER COBB.

So early as 1837, Poisson produced his general equations for determining the influence of the earth's attraction and rotation on the apparent motion of a projectile, and he applied them to the case of a material point constrained to move on a given curve and attached to the surface of the earth, omitting the effects of friction and the resistance of the air.

In 1859, Ferrel published in *Runkle's Mathematical Monthly* his celebrated paper on the *Motions of Fluids and Solids on the Earth's Surface*, in which he stated that, "In whatsoever direction a body moves on the surface of the earth, there is a force arising from the earth's rotation which deflects it to the right in the northern hemisphere, but to the left in the southern."

Karl E. von Baer, in a paper, *Ueber ein allgemeines Gesetz in der Gestaltung der Flussbetten*, published in the bulletin of the Imperial Academy of Sciences of St. Petersburg, in 1860, showed that the observed changes of position in streams might be explained as a consequence of the earth's rotation; yet the makers of our scientific text-books have not taken the pains to give a correct, or rather, a complete, statement of the true value of this deflective force. Dana states it clearly and correctly in his Manual of Geology;* but Geikie† speaks of it as an *easterly*, a *westerly* deflection, seeming to regard it as a getting left behind, and the same expression is used by Reclus‡ in speaking of the rivers of Gers.

Von Baer's explanation does not account for the fact that

*Third edition, p. 650. †Third edition, 1893, pp. 15, 16. ‡*La France*, pp. 115, 116.

rivers flowing east or west have their banks worn away in the same manner as those flowing north or south. A body at rest upon the earth, and free to move in any direction upon it, "is maintained in equilibrium by attraction directed towards the earth's center, and centrifugal force directed away from the axis. If the centrifugal force ceased, the body would evidently move towards the nearest pole as down a hill. From the poles to the equator may therefore be regarded as uphill—bodies free to move being prevented from going down towards the poles by centrifugal force. Suppose now a body to move from west to east—that is, in the same direction as the earth revolves; the centrifugal force of the body is increased, and there is a tendency to move uphill towards the equator. If the motion be from east to west, the centrifugal force is diminished and the body tends towards the pole. In each case the tendency is towards the right in the northern hemisphere and towards the left in the southern."*

Admitting the sufficiency of the terrestrial rotation for the deflection of streams, we must look for our examples to those regions where the strata are essentially horizontal and horizontally homogeneous. McGee, in his paper on the geology of the Chesapeake Bay, says: "It may be noted in passing that, throughout its gorge, the Susquehanna River hugs its left shore the more closely, and apropos to the hypothesis of the dextral deflection of rivers by terrestrial rotation (commonly known in Europe as Baer's law), specifically applied by Kerr to the water-ways of the Middle Atlantic slope, and recently discussed in more general terms by Gilbert, Davis, Hendricks, Bains, and others, it may be mentioned that the different water-ways of the Middle Atlantic slope are not only inconsistent in their behavior at and above the fall-line, but in many cases the same stream has not behaved uniformly since the excavation of its gorge was initiated."†

*A. C. Bains, in a paper read before the Philosophical Institute of Canterbury, New Zealand, October 4, 1877.

†Seventh annual report of the Director of the United States Geological Survey, p. 554.

McGee's objection is done away with by the fact that the Susquehanna River is not situated in a region of the required horizontal homogeniety, and that if it now shows a preference for its left bank, that preference is probably an inheritance from the time when the favoring conditions did exist, before its superimposition upon the Wiconisco and Tuscarora-Mahanoy synclines, when the course of the river was the reverse of what it is now, and its present left bank was its right bank.*

Turning now to the regions of horizontal homogeniety, we see that their streams all show this right or left deflection, according as they are north or south of the equator. Such a region is that where the phenomenon was first observed, in the middle and lower courses of the Volga. Here all of the conditions are most favorable; the river has a considerable length of course, and the mass of water is powerful enough to clear away any obstacles; "there are enormous floods which periodically increase the force of erosion in the currents, and the cliffs are composed of friable rocks."† Two centuries ago the principal mouth of the Volga flowed directly to the east of Astrakhan; since that time the great current has successively hollowed out for itself fresh beds, tending more and more to the right, and at the present day the branch navigated by vessels turns to the south-south-west. The Volga, up to its near approach to the sea, has a high right bank, and the erosion-valley, which slopes gently on the left, is bounded by rather abrupt cliffs on the right.

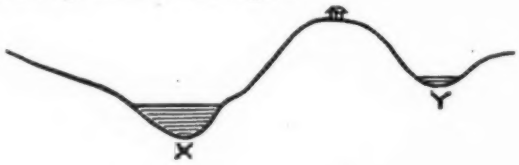


FIG. I.—THE VOLGA AND THE RWJAGA.

* See Rivers and Valleys of Pennsylvania, W. M. Davis, *National Geographic Magazine*, Vol. I. p. 47, 1889.
† Von Baer.

In the diagram, which is taken from von Baer, we have at X the Volga. Its left bank is flat, or only gently sloping; the right rises irregularly to a considerable height and falls down on the other side, not nearly so far to the river Rwjaga at Y, and then rises slowly again. The Volga is flowing from the observer, and the Rwjaga towards him, and there is barely room for a habitation between them, "where it depends upon the whims of the kitchen maids whether the dish-water which is daily poured out flows immediately into the Volga, or whether it reaches the same destination in a round-about course of four hundred versts. This statement may seem exaggerated, but it is literally true."*

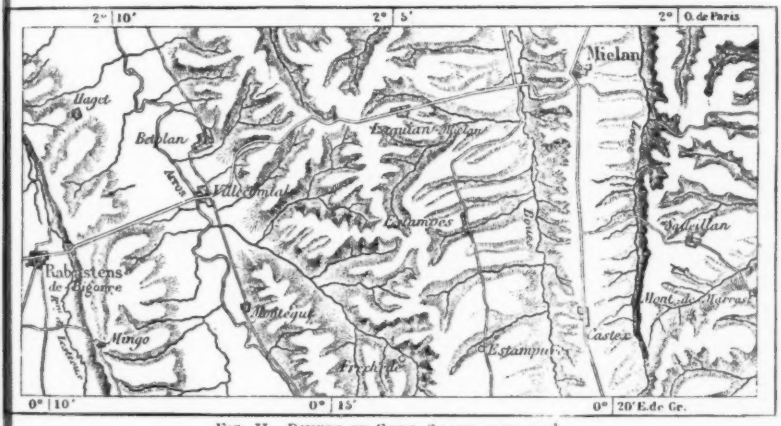


FIG. II.—RIVERS OF GERS. SCALE, 1: 150,000.†

In the southern part of France, in the province of Gers, we have a gently sloping plain, an old river delta that has been lifted up, where streams can flow off in every direction down the slope, and take such courses as they may. Here the right-hand tendency is shown to perfection. The streams have their longer tributaries on the left, and their right banks rise in bluffs.

*Von Baer, St. Petersb. Bull. Sci. II., 1860, col. 230.
†From *la Carte d'Etat-Major*, reprinted in Reclus's *Nouvelle Geographie Universelle*, 2.

Turning to the United States and selecting a few places where the necessary horizontal homogeniety is found, we have no trouble in pointing out examples. "The south side of the island of Long Island is a plain of remarkable evenness, descending with gentle inclination from the morainic ridge of the interior to the Atlantic Ocean. It is crossed by a great number of small streams which have excavated shallow valleys in the homogeneous modified drift of the plain. Each of these little valleys is limited on the west or right side by a bluff from ten to twenty feet high, while its general slope on the left side merges imperceptibly with the general plain. The stream in each case follows closely the bluff at the right."*

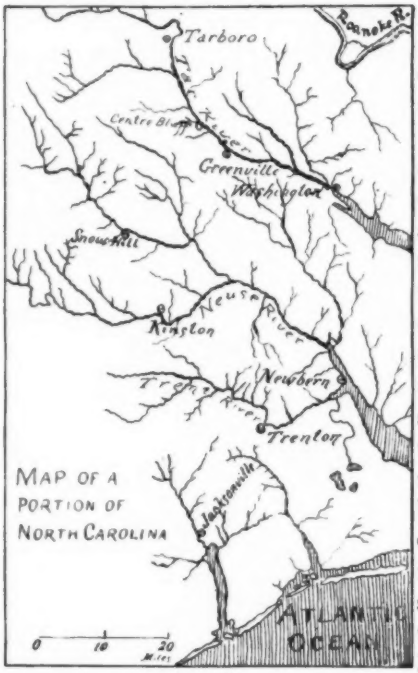


FIG. III.

The peculiar topography of the eastern portion of the Carolinas, where the necessary conditions exist, has been pointed out by Tuomey and by Kerr. Here the streams have cut through the Quaternary and Tertiary formations, and well into the Cretaceous, and in every instance they present the high right bank, with the low sloping country on the left; and, as may be seen by the sketch-map, the tributaries of the Roanoke, the Tar,

*G. K. Gilbert, *Am. Jour. Sci.* 3d xxvii. 431.

the Neuse, and the Cape Fear run well back to the streams lying to the northward. In the case of these streams the dip of the strata is not such as to aid in the making of the right bank higher. Such conditions are represented in Fig-

FIG. IV.

FIG. V.

FIG VI.

ure IV. In Figure V the arrangement of the strata is such as to hinder rather than help the deflective effect of rotation; and yet this is the structure of the Carolina region, as shown in Figure VI, which is taken from Kerr.* But the rocks here are imperfectly lithified, and so friable as to yield readily to the influence.

The Mississippi River does not act consistently throughout its course, but in most instances its right bank is higher except where the prevailing winds are from the north-west. At Burlington, Iowa, the east or left side is low, and the trains of the C., B. & Q. Railroad reach the bridge over embankments and trestle-work, but run directly into the town on the high right bank of the river. At Dubuque just the opposite conditions exist.

Turning to regions south of the equator, we find in the plains of Canterbury, New Zealand, the requisite conditions. The Rakaia River cuts through Quaternary strata and into late Tertiary, and its left bank is its steeper bank. This is also shown in all the rivers entering Tasman Bay through strata of the same age, and there are doubtless many other cases in the same region. I have not at hand the maps and geological report for that region.

* Geology of North Carolina, Vol. I, 1875, p. 10.

Those who are familiar with the map of South America, where the older rocks have been decomposed for great depths *in situ*, and where the younger rocks are but imperfectly lithified over great areas, must recall the fact that nearly all the streams have their longer tributaries on the right, showing a left-hand deflection of the main streams.

The cases cited serve my purpose of showing that wherever the conditions permit the influence of the earth's rotation is perceptible.

THE STONE ARCH.

BY WILLIAM CAIN, C. E.

The theory of the voussoir arch has long exercised the ingenuity of mathematicians, and it may prove interesting, before giving the results of some recent investigations by the writer, to give brief statements of some of the leading theories that have been proposed, from time to time, as indicating the path followed in such original investigations.

As we should naturally expect, the theories proceed from the simplest, where the arch is assimilated in its action to a wedge, to the most complex, where the deformation of each individual stone under stress is considered.

In most of the theories hitherto proposed the arch is regarded as inelastic and the stones infinitely strong, so that the resultant thrust of one part of the arch against another can take place along the very edge of a joint without crushing ensuing.

These simple hypotheses unfortunately do not express the actual conditions, which involve the consideration of the elasticity of all the materials entering into the construction of the arch, the fit of the stones, thickness and

degree of hardness of the morter joints (if any), settlement and time of striking of the centers, the manner in which the loads are transmitted to the arch ring, the relative density of the various stones, and finally the dynamic effect of moving loads. The true conditions are thus seen to be so complex as to make the true solution of the stone arch one of the most difficult, if not the most difficult, in all the range of the application of the laws of mechanics to engineering structures.

The latest theory, given further on, includes the most essential of the conditions just outlined, but not all of them; so that it is not proposed as a final and complete solution of the problem, but as one sufficiently near to make the results of decided practical value, approximating to the exact truth, as the hypotheses are more nearly realized in the construction of the arch ring.

Recurring now to earlier theories of the arch, Lahire, at the beginning of the last century, considered that the arch would break along "joints of rupture," half way between the crown and the springing, and he assimilated the action of the upper part to that of a solid wedge, tending to slide downwards along the joints of rupture, which last were considered perfectly smooth, so that the pressure there was directed normally to the point.

This very crude hypothesis was adopted by Eytelwein, who, however, found that joint of rupture for which the pressure exercised against an abutment was a maximum. As a matter of fact, friction can be exercised at any plane joint, which Eytelwein only imperfectly considers; but admitting it, the direction of the thrust at any joint of rupture becomes indeterminate, so that apart from other defects, the theory gives no definite solution.

Coulomb, in 1773, made a great advance by considering that an arch could not only fail by *sliding* along some joint, but also by *rotation* along the edges of certain joints.

He assumed the horizontal thrust at the crown always to pass through either the upper or the lower edge of the joint and found its minimum value, *so that no rotation would occur* about the lower or upper edge of any joint below the crown and such that no sliding could occur along any joint.

It is not necessary to explain the ingenious method by which the true thrust, after his theory, was ascertained. The theory was a marked improvement over the wedge theory, and it has been followed by a host of authors, with various improvements, even up to the present day.

As the thrust either at the crown joint or the lower joints of rupture cannot act along an edge without crushing ensuing, it is evident that the true positions of the thrusts at these critical joints has not been correctly ascertained; further, there is nothing in the theory to raise the indetermination.

The next advance in the theory was made by certain authors who used *a funicular polygon* in studying the resistance at the various points, a method which is still the basis for the analytical treatment of the arch.

It required but an additional step to see that *the curve connecting the centers of pressure* on every joint of the arch ring (to which the proper "funicular polygon" approximates for segmental arches) was a surer test of the stability of an arch ring and that, *in a stable arch*, it must always be possible to draw some "curve of resistance" (as the curve connecting the centers of pressure is called) within the limits of the arch ring, or, for safety, within much narrower limits.

The exact location of this curve, for any arch, loaded in any manner, will completely solve the problem for that arch; but where an infinite number of possible curves of resistance can be drawn within the arch ring (or narrower limits), all varying in the point of application, direction or

intensity of the thrust at the crown, it is evident that some additional principle must be introduced to enable us to choose the true one. Mosely introduced for this purpose *the principle of the least resistance*, which at once fixed the true curve as the one corresponding to the minimum horizontal thrust. This caused the results to agree with those of Coulomb, in most cases, though not in all, as the curve so determined does not, for some arches, pass through either edge of the crown joint, as Coulomb's theory requires.

In this and previous theories the arch and load were taken as symmetrical with respect to the vertical through the crown which thus restricts the theory to structures having fixed loads and rendering it of little service in the investigation of the strength and stability of road or railroad arch bridges subjected to a moving load, which produces a maximum distortion when placed over one haunch of the arch; further, the theories demanded incompressible voussoirs of infinite strength, which do not exist.

Scheffler developed very completely the theory of curves of resistance for the least horizontal thrust, for both symmetrical and unsymmetrical arches and loading; but as his theory requires the thrusts at the critical joints to pass through the very edges, it cannot apply to ordinary stones, where crushing would result, as a matter of course. Now, as crushing does not occur at the joints in well-designed arches, it follows (without other considerations) that Scheffler's theory must, at least, be modified. The writer did this in introducing the theory to American readers in 1874, by empirically limiting the curve of resistance to the middle third of the arch ring. With such a restriction, for a joint with mortar, there would be no tension exerted anywhere along the joint, and for a joint without mortar there would be a compression throughout the whole length of the joint, so that no joint would open. Such restrictions had already been suggested by Rankine, Woodbury

and others, as leading to safer results in proportioning an arch. The writer, however, called attention to the fact that, as in most well-built arches, the joints did not open, therefore, by experiment on a big scale, it was shown that the true curve of resistance in arches, as generally built, did not leave the middle third; hence, for usual depths of key-stone and usual loads, the true curve of resistance was found somewhere in the middle third. Its position in the middle third of the arch ring could be provisionally found by the principle of least resistance, though it was admitted that its exact position was dependent on the deformation of the arch ring under stress, due to its elasticity, the laws of which were not known at the time.

However, after mathematicians had developed a true theory of the *solid elastic arch*, "fixed at the ends" in position and direction, it seemed possible to apply it to the voussoir arch, and thus locate accurately the true curve of resistance, provided the following conditions were fulfilled:

1. No mortar was to be allowed between the arch stones or voussoirs;

2. The arch stones must be cut so perfectly that they will fit exactly, when not under stress, in place on the "center"—supposed unyielding;

3. Under these circumstances the curve of resistance, determined after the theory of the solid arch for the full sections of the arch ring, must lie in its middle third. If this last condition does not obtain, the solution is still possible, though the full sections cannot be used at certain joints, which involves a tentative method of finding the parts of the joints under stress and the resulting resistance curve, which makes a practical solution of the case much more difficult.

Under the conditions assumed above the deformation of the voussoir arch is exactly that of the solid arch and there can be no question as to the theory applying.

It is admitted, however, that it is difficult to cut the stones with the exactness demanded, and in addition, there will be a slight yielding of the centers, though the stones can easily be cut to bear along the whole length of joint when placed in position on the centers after they have yielded somewhat, as it only requires a close fit of the keystone after the other stones are in place.

If thin cement mortar joints be used, that are allowed to harden perfectly before the centers are removed, the arch ring is assimilated completely to a solid arch, except that in the theory the successive blocks of cement and arch stones with their different moduli of elasticity must be considered, making the solution very complex. It would seem though that for very thin joints the theory pertaining to a homogeneous arch of stone should approximate sufficiently near to the truth to give results of practical importance.

For thick mortar joints of common mortar or for brick arches the theory proposed may be a rude guide, but it is not pretended that it can be anything but a rough approximation to the truth, so that the depth of key for such arches had better be increased empirically over the depths given by the theory above for a homogeneous solid arch.

The theory of the solid arch supposes immovable abutments and it requires three conditions to be fulfilled when the *arch ring* is under stress from its own weight and the weight of backing, roadway, etc., and any loads that may be placed on it in any position:

1. The end tangents, at the springing, to the center line of the arch ring, must remain fixed in direction;

2. The deflection of one end of the arch ring below the other, due to its deformation under stress, must be zero;

3. There must be no change in span due to the deformation of the arch ring.

Analytical theories of the solid arch have been developed by Winkler, Greene and others, and the graphical solution has been given by Prof. H. T. Eddy, to which the writer has contributed his mite.

In *Van Nostrand's Engineering Magazine* for January and November, 1879, the writer claimed that the theory of the solid arch was the most exact solution of the voussoir arch, and a graphical treatment was given in the last named article. In the same year Castigliano, Winkler and Greene referred the treatment of the voussoir arch to that of the solid arch, and finally, in 1893, the writer, in the second edition of "Theory of Voussoir Arches," has given extended applications of the theory of solid arches to voussoir arches by two distinct methods, one founded on the analytical method in part and the other entirely graphical.

These methods were independently applied to a number of stone arch bridges, whose rise was one-fifth the span, for a loading known as Cooper's "Class Extra Heavy A," so placed as to produce the maximum departure of the resistance curve from the center line of the arch ring, and the results appear to be of such importance as to offer some apology for writing this article.

In the stone arch bridges examined the specific gravity of the voussoirs was assumed at 140 pounds per cubic foot, and the density of the spandrel backing was taken at eight-tenths that of the voussoirs. The weight of this backing and any loads on the bridge was assumed to be transmitted vertically to the arch. It is true that this may not be exactly true; in fact, the spandrel may act as an arch itself to some extent, still such additional security may be supposed to neutralize the *dynamic* effect of moving loads, the *static* effect of the loads being met by designing the arch ring, supposed of constant section throughout, so that for the most unfavorable position of the load, for *any* joint, the line of the centers of pressure on the various joints should

be contained within the middle third of the arch ring, and for the joint where the departure was greatest this line should just touch the middle third limit. A slight decrease in the depth of key would thus cause the true resistance curve to pass slightly outside the middle third at some joint or joints.

The proper depth of key to meet this last condition was found tentatively by assuming successive depths of key for the same span until one was found in which the true resistance curve could just be inscribed in the middle third for the most unfavorable position of the live load. Only two trials were needed in any case.

It was found for the arches so designed that no sliding could occur along any joint. The maximum stress, in tons per square foot, at the most compressed edge, varied from nine for the twenty-five foot span to thirty-six for the 150 foot span.

Thus the arch ring possessed the requisite stability for an arch of sandstone or limestone and an excess of stability for granite, whose weight per cubic foot is over the 140 assumed. For material weighing over 140 pounds per cubic foot the depth of key given below can be slightly diminished or a heavier load can be assumed.

The live load assumed is known in Cooper's Specifications as "Class Extra Heavy A."

We give below the distances in feet from the front pilot-wheel to each pair of wheels in turn, and on the same line the weight of the pair of wheels in tons of 2,000 pounds:

Pair of	Pilot-wheels	0	feet	8	tons.
"	Driver-wheels	8.1	"	15	"
"	"	13.83	"	15	"
"	"	18.33	"	15	"
"	"	22.83	"	15	"
"	Tender-wheels	29.92	"	9	"
"	"	34.75	"	9	"
"	"	40.42	"	9	"
"	"	45.25	"	9	"
"	Pilot-wheels	54.25	"	8	"

The second locomotive can be located from the last pair of pilot wheels.

For spans of fifteen feet and under, a pair of wheels carrying forty tons was used as producing a more hurtful effect. The above load was placed over one-half of the arch, roughly speaking, the heaviest part being over the center of the haunch. Its exact position, however, was determined very carefully so as to produce the most hurtful effect upon the arch ring.

An approximation to this load was made by omitting the pilot-wheels in some of the computations. Also by the independent partly analytical treatment, used as a check, the load on drivers was supposed uniformly distributed as well as that on the tenders, and for convenience the lengths of each portion were slightly changed to suit the divisions of the arch required in the theory. The pairs of wheels were supposed to bear on cross-ties eight feet in length, so that only one-eighth of this load was supposed to bear on a slice of the arch contained between vertical planes perpendicular to the axis of the arch and one foot apart.

The depths of key so determined for arches of constant section and rise $= \frac{1}{5}$ span are given in the following table, the determinations for the spans 12.5, 25, 50, 75, 100, 125 and 150 having been found directly, the others by interpolation from these values. All dimensions are in feet.

RISE EQUAL ONE-FIFTH THE SPAN.

Span.	Key.	Span.	Key.	Span.	Key.
5	1.96	55	3.7	110	5.80
10	2.12	60	3.9	115	5.95
12.5	2.20	65	4.1	120	6.10
15	2.27	70	4.3	125	6.25
20	2.43	75	4.5	130	6.40
25	2.60	80	4.7	135	6.55
30	2.77	85	4.9	140	6.70
35	2.95	90	5.1	145	6.85
40	3.13	95	5.3	150	7.00
45	3.30	100	5.5	155	7.15
50	3.50	105	5.65	160	7.30

Stone arches of the dimensions given should be perfectly safe against rotation or sliding anywhere for the very heavy rolling load assumed; but the depth of key should not be less than the values given, as the true line of resistance, for certain positions of the moving load, will then pass outside the middle third at certain joints, and although the arch may be stable, the factor of safety is reduced too much and the joints of rupture may open, thus admitting the infiltration of water, which is not desirable; besides, for the larger arches, the maximum intensity of stress at the edges of the joints of rupture may exceed safe limits. In fact, this intensity for the 150-foot span for a 7-foot key is 36 tons per square foot—an admissible value for good solid voussoirs, well laid, though not at all for rubble construction or for brick, except, perhaps, the very best pressed brick. From experience it would seem that an outside limit for this intensity for good granite should be about 46 tons per square foot.

The arch can preferably be built by increasing the radial length of joint as we go from the crown to the springing, as is done in arches of large span, in which case the depth of key-stone can be decreased somewhat below the tabular values with the same security against overturning, sliding or crushing.

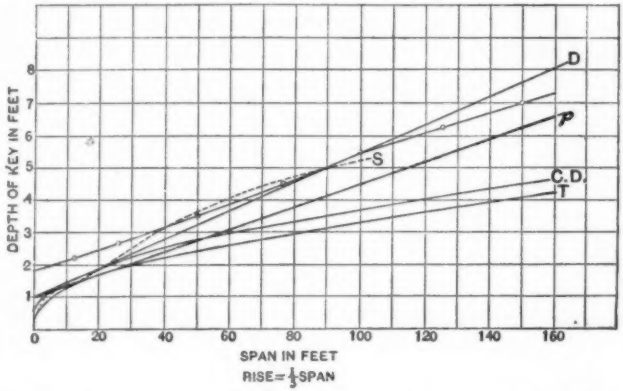
In case the abutments or piers yield somewhat at the top from defective foundations the depth of key should be greater than as given in the tables.

The formulas that have been proposed for depth of key by many authorities are not founded on theory, but on the successful practice of the past, particularly for common road bridges and railroad bridges subjected to the lighter loads of several decades ago.

The writer has been convinced for a number of years that the dimensions given by many of these formulas (in current use to-day) are very inadequate for stone arches subjected to the very much heavier rolling loads of to-day, and that arches so proportioned probably are saved from destruction only from the extra resistance afforded by the span-

drels. On that account he was led to undertake the very serious labor of computing the depths of key for a number of arches after the theory proposed, and to compare with the results given by some of the empirical formulas.

The results are shown graphically in the figure, the line through the small circles (which is nearly straight) being plotted from the values given in the table above.



The depths of key proposed by the following authors are given by the ordinates to the various lines for the corresponding spans given by the horizontal lines: Trantwine (line T), Croizette-Desnoyers (line C-D), Perouet (line P), Scheffler, by interpolation from his tables (line S, dotted) and Dejardin (line D).

These results refer to materials of only average strength (second-class masonry for the Trantwine line) and vary very greatly; thus for an arch of 160 feet span and thirty-two feet rise Trantwine gives a depth of key of 4.3 feet, whereas Dejardin requires eight feet and then increases the radial length of joint according to the secant of the inclination of the joint to the vertical as we approach the abutment.

The theoretical depths of key agree more nearly with those of Dejardin and Scheffler than with any of the others, though it is in excess for the smaller spans over any of the empirical results, as should naturally be expected.

It is respectfully submitted to constructors that most of the formulas in current use are inadequate to give a proper depth of key for the very heavy rolling loads of to-day, although it is thought that such formulas may still serve the purpose of a rough guide in the design of common road bridges, unless heavy concentrated loads, as steam road-rollers, are to pass over them. In all cases it is best to use the formulas for an assumed key and then by a theoretical treatment determine the proper key by one or two trials.